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REVEALING THE EXTRA-HIGH DUCTILITY AND TOUGHNESS OF MICRO-DUPLEX MEDIUM-MN STEEL IN A LARGE TEMPERATURE RANGE FROM 200℃ TO -196℃

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ABSTRACT

A medium-Mn steel (0.2C5Mn) was processed by intercritical annealing at different temperature (625℃ and 650℃) after forging and hot rolling. The microstructures were characterized by transmission electron microscopy and the mechanical properties were measured by tensile tests and impact tests at different temperatures. It was found that an ultrafine grained micro-duplex structure existed with austenite and ferrite laths formed by means of an austenite reverse transformation during intercritical annealing (shortly called ART-annealing). Ultrahigh ductility (total elongation larger than 30%) could be obtained in the temperature range from 200℃ to -196℃. And significantly delayed transition from ductile to brittle and no less than 200J impact toughness at -40℃ could be obtained in the ART-annealed medium-Mn steel. Based on the analysis of microstructure and mechanical properties, the enhanced ductility in the full temperature range could be ascribed to the phase transformation effect of austenite (TRIP effects), while the delayed ductile to brittle transition could be attributed to the enhanced austenite stability.

1. INTRODUCTION

Steels are required to provide high strength, high ductility, and high toughness under different temperatures covering a large range, for example, vehicles, vessels, and pipelines work from a low temperature below -100℃ to a high temperature close to 100℃. Thus a thorough understanding on the knowledge of mechanical properties at varied temperature is essential for the design and application of steels. Recently, new pipeline steels have been proposed to resist process, thus the carbon content in the austenite ~0.82% in steel 625 and 0.55 % in steel 650 could be estimated under the assumption that the carbon is about 0.02% in ferrite. And the Mn content in the austenite is calculated to be ~10.0% in steel 625 and 9.0% in steel 650 by the commercial software of Thermo-CALC, which is in a good agreement with the experimental values (Lis and Lis 2008). Based on these data, the start temperature of the martensite transformation (Ms) is ~-94^{O}C for the steel625 and ~25℃ for the steel650 according to the equation of Ms=499-316.7C%-33.3Mn%. The strain induced martensite transformation start temperature is about 25℃ for the 625steel and 100℃ for the 650steel.

It can be seen from Fig.4 that the start decreasing temperature of the impact toughness is about -~25℃ for the 625steel and ~100℃ for the 650steel. The ductile to brittle transformation temperature (50% impact toughness decreasing) is about ~-90℃ for the 625 steel and ~30℃ for the 650 steel. It is very interesting that the start falling temperature of the impact toughness is nearly the same as that of the starting temperature of the strain induced phase transformation (Mσ), whereas the ductile to brittle transformation temperature (half toughness temperature) is nearly the same of that the starting transformation temperature of martensite (Ms) for both steels. This means that the deformation behaviour of the ductile to brittle transformation measured by impact toughness is mainly controlled by the stability of the austenite in the medium-Mn steel treated by intercritical annealing, which provides us the way to design a high ductility and high toughness steel by the control of the stability of the austenite in the multiphase structured steel.

Table 2. Phase transformation and ductile to brittle transformation temperatures

Steel	Half toughness temperature	Ms	Toughness start decreasing	Mσ
steel625	-90℃	-94℃	25℃	25℃
steel650	30℃	25℃	100℃	100℃

5. CONCLUSIONS

In this study, a medium-Mn steel (0.2C5Mn) was processed by relatively long-time ART-annealing at different temperatures. The conclusions can be made as follows.

1. Long time annealing in the intercritical region results in a large volume fraction of austenite with an ultrafine grain size in the medium-Mn steel.
2. The medium-Mn steel after long time intercritical annealing has a good combination of strength, ductility and impact toughness in a large temperature range from -196℃ to 100℃.
3. The extra high ductility of the studied steel could be ascribed to the TRIP effects of the large content austenite with an ultrafine grain size.
4. The deformation transition of ductile to brittle can be related to the stability of the retained austenite based on the experiments and calculation.

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